DIVERSITY OF STRESS RANGES IN CABLES OF CABLE-STAYED BRIDGE DUE TO TRAFFIC LOADS AND FAR-FIELD SEISMIC EXCITATION

LEE CHONG HOE

B. ENG (HONS.) CIVIL ENGINEERING

UNIVERSITI MALAYSIA PAHANG

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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(Student's Signature)

Full Name : LEE CHONG HOE

ID Number : AA15290

Date : 30 May 2019

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LEE CHONG HOE

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ABSTRAK

Secara amnya, analisis kelesuan di jambatan memberikan penekanan yang besar kepada beban hidup kitaran dalam bentuk beban lalu lintas dan angin yang bergerak. Walau bagaimanapun, peningkatan aktiviti seismik di rantau ini menyebabkan struktur keluli lebih terdedah kepada fenomena kelesuan di mana ianya menambahkan beban kitaran yang mana dapat mengurangkan jangka hidup kelesuan mereka. Dalam kajian ini, analisis kelesuan terhadap jambatan kabel dengan mengambilkira bebanan secara statik dan dinamik dilakukan dengan memberi tumpuan kepada variasi tekanan dalam kabel kerana kesan beban lalu lintas yang bergerak dan galakan gerak tanah. Reaksi dinamik jambatan tertakluk kepada beban lalu lintas dan pergerakan bawah tanah yang secara mendatar dan menegak. Beban trafik yang digunakan adalah berdasarkan Fatigue Load Model (FLM) yang mana digunakan untuk menghasilkan beban kelesuan yang setara dengan trafik sebenar. Dalam kajian ini, Fatigue Load Model 4 (FLM4) telah digunakan sebagai bentuk beban trafik yang digunakan kerana kemampuannya menghasilkan pelbagai hasil dengan ketepatan yang mencukupi. Dua bentuk konfigurasi trafik akan digunakan; beban lalu lintas dalam konfigurasi Tunggal Lori dan konfigurasi Konvoi Lori. Tiga set usul tanah menegak jauh dari pelbagai magnitud juga telah digunakan dalam analisis terhadap jambatan kabel ini. Keputusan kajian ini menunjukkan pengaruh ketara beban trafik terhadap variasi tekanan jambatan kabel yang mempunyai kesan yang ketara disebabkan oleh pergerakan tanah dalam tempoh '*return period*' yang dijangkakan. Dalam kajian ini didapati bahawa kabel yang lebih hampir dengan tiang jambatan dan kabel di hujung rentang sisi jambatan mengalami perubahan yang ketara dari segi perbezaan tekanan apabila terdedah kepada beban lalu lintas dalam konfigurasi Tunggal Lori akibat interaksi setempat antara kabel dan penyebaran beban yang lebih kecil. Walau bagaimanapon, kombinasi beban yang melibatkan beban lalu lintas dalam konfigurasi Konvoi Lori menghasilkan peningkatan yang ketara dalam julat tekanan maksimum yang dialami oleh kabel yang disambungkan kepada rentang utama dan juga '*backstays*' yang disambungkan kepada tiang dan '*anchorange'* berhampiran dengan hujung rentang sisi jambatan. Berdasarkan keputusan analisis yang dilakukan, penempatan beban bergerak dalam konfigurasi ini mempunyai spektrum yang lebih luas dari segi kesannya pada jambatan kabel. Selain itu, hasil analisa berdasarkan pergerakan tanah dari magnitud yang berbeza telah menunjukkan bahawa peningkatan kepada kekuatan gempa bumi yang mana secara langsung akan meningkatkan peningkatan tekanan maksimum yang dialami oleh kabel di sepanjang jambatan.

ABSTRACT

Generally, the analysis of fatigue in bridges places a large emphasis on cyclic live loads in the form of moving traffic and wind loads. However, the rise in seismic activities in the region increases the exposure of steel structures towards additional cyclic loads that could reduce their fatigue life. In this study, the static and dynamic behaviour of a cable-stayed bridge in terms of fatigue of steel elements are addressed by focusing on the stress variation in stay cables due to the effects of moving traffic loads and ground motion excitations. Dynamic responses of the bridge are subjected to moving traffic loads and ground motions considering horizontal and vertical motions from far-field faults. The applied traffic loads are based on Fatigue Load Model (FLM) to produce fatigue damage equivalent to actual traffic. In this study, Fatigue Load Model 4 (FLM4) have adopted as a form of applied traffic load due to its ability to produce a wider range of results with sufficient accuracy. Two forms of traffic configuration will be used: traffic loads in Single Lorry configuration and Convoy Lorry configuration. A suite of three far-field vertical ground motions of varying magnitude has been used. Effects of traffic loads and ground motion on variations of nominal stress in stay cables are presented. The results of this study revealed the notable influence of traffic loads on stress variations of cable-stayed bridges with significant effects due to ground motions scaled to the expected return period. It has been found that stay cables closer to the pylons and side span supports experienced a significantly large stress range when exposed towards traffic loads in Single Lorry configuration due to the localized interaction between the stay cables and narrower load distribution. In contrast, load combinations involving traffic loads in Convoy Lorry configuration resulted in a substantial increase in the maximum stress ranges experienced by stay cables connected to the main span as well as backstays connecting the pylon head to the anchorages near the side span supports. Based on the results, the placement of moving loads in this configuration has a wider spectrum in terms of its effect on the cable-stayed bridge. Moreover, analysis results based on the application of ground motions of different magnitudes have shown that increments to the strength of an earthquake would tend to increase the maximum stress ranges experienced by stay cables throughout the cable-stayed bridge.

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LIST OF SYMBOLS

MPa	Mega Pascal
GPa	Giga Pascal
m	metre
mm	millimetre
mm^2	area
km	kilometre
s	seconds
ms^{-1}	velocity
w_p	weight per unit length
ρ_s	density
g	gravitational acceleration ($9.81ms^{-1}$)
A_T	cross-sectional area
$F_{p,o}$	Initial post-tension force
γ_{eq}	Equivalent Tangential Modulus of Elasticity
N	Newton
N/mm^2	Pressure/Stress
kN	Kilo Newton
σ_m σ_α	Stress
M_w	Moment Magnitude Scale
%	Percent
C	Carbon
Si	Silicon
Mn	Manganese
Cu	Copper
Ni	Nickel
Cr	Chromium
P	Phosphorus
S	Sulphur
E	Modulus of Elasticity
R_{epi}	Epicentral Distance

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
BA	Button Anchorage
HDPE	High Density Polyethylene
UTS	Ultimate Tensile Strength
Y_s	Yield Strength
MBP	Minimum Breaking Point
E	East
N	North
S	South
PGA	Peak Ground Acceleration
GMPE	Ground Motion Prediction Equations
PSHA	Probabilistic Seismic Hazard Maps
PE	Probabilities of Exceedance
RP	Return Period
Nos.	Numbers
BS	British Standard
EN	Eurocode
FLM	Fatigue Load Model
N_{obs}	Number of estimated heavy vehicles per year per slow lane
PEER	Pacific Earthquake Engineering Reseach
NGA	Next Generation Attenuation
USGS	United States Geological Survey
CESMD	Center for Engineering Strong Motion Data
H	Horizontal Axis
V	Vertical Axis
2D	Two-dimension
3D	Three-dimension
LHS	Left Hand Side
RHS	Right Hand Side
DL	Dead Loads
PS	Post-tension

SL	Single Lorry
CL	Convoy Lorry
KCL	Koceali Bornova
DNL	Denali
SSN	San Simeon
EQ	Earthquake
MET	Malaysia Meteorological Department

CHAPTER 1

INTRODUCTION

1.1 Preamble

Since the early 1940s, longer bridges became very important due to the requirement of a large amount of traffic use daily from one place to another place. The long–span bridges not only to enhance the efficiency of the entire transportation system globally but also to reduce the travel time that could take hours to arrive. There are three types of long-span bridges based on the main span length which are:

1. Arch Bridge (max span of 552m)
2. Cable-Stayed Bridge (max span of 1104m)
3. Suspension Bridge (max span of 3911m)

Arch bridges are known by their arch or curved structure that provides structural support to the entire structure. Due to the nature of the curved shape, vertical loads that comes from both the structural self-weight and imposed loads such as traffic loads are transferred along the arch to both ends of the abutments. The result of such structure allows the vertical loads to be distributed uniformly along the entire span of the bridge, ensuring mutual support among all parts of the structure. In conventional thrust arches, this would result in greater reliance on horizontal restraint of the supports, therefore imposing a significant magnitude along the horizontal component. This in return requires the support of the arch to be anchored into foundation material that is competent in bearing the loads such as rocks. However, rocks are not always available for the use of foundations in such a way that there exists a requirement for significant engineering that is un-economic towards the foundation as compensation. In response to such limitations, tied-arch bridges introduce the deck as a tie member that takes the forces along the horizontal component and reducing the forces that have to be resisted by the supports to predominantly vertical loads (Ayres C., 2015). Consequently, the application of a tie enables arch bridges to achieve longer spans as they are no longer limited by the supports but rather on the properties of the materials used. Holding the current record for the world's longest arch bridge, is the Chaotianmen Bridge that spans 552 meters across the Yangtze River in Chongqing, China as presented in Figure 1.1.

Figure 1.1: Chaotianmen Bridge (China Communications Construction Company Ltd., 2010)

Meanwhile, suspension bridges utilize large cables that pass over the cable saddles on the towers and are anchored on both ends of the bridge to suspend the bridge deck. The main cables sustain tensile forces that transfer from the deck through hanger cables and transfers them into both the towers and the anchorages where the towers are designed to sustain forces that are dominant along the direction of gravity and the anchors resist a larger magnitude of horizontal forces. In contrast, allowable stress of materials is one of the limitations when it comes to the maximum span length of bridges. Till this day, steel and concrete remain as the predominant material in terms of the construction of long-span bridges due to their availability and continuous improvement. To date, the Akashi Kaikyō Bridge in Kobe shown in Figure 1.2 holds the title for the world's longest suspension bridge at a span of 1991 meters.

Figure 1.2: Akashi Kaikyō Bridge, Kobe. (Rötzel K., 2005)

In the case of the cable-stayed bridge, the maximum span is limited by the compressive stress in the bridge deck with the deck, pylons and stay cables being the main load carrying members. Stress components in bridge decks are comprised of axial stress and flexural stress due to the bending moment induced by the vertical and lateral loadings. The arrangement of stay cables consequently results in the increase of axial forces in the deck with a relative decrease in the distance with the towers (Gimsing, N. J. & Georgakis, C. T., 2012).

In addition, torsional stiffness is crucial in resisting torsional oscillations that originates from eccentric loadings and aerodynamic actions. Conventional box girders present in most cable-stayed bridges are capable of providing sufficient resistance to massive forces. Furthermore, increments to the torsional rigidity of girders can be achieved by spacing out the distance between two cable planes. This ties in directly to the option of increasing the cross-sectional size of the girders to increase its allowable stress and effectively enhances the spanning ability of cable-stayed bridges (Gimsing, N. J. & Georgakis, C. T., 2012).

Cable-stayed bridges are comprised of cables that connect the bridge girder to the pylons to form a series of overlapping triangles as depicted in Figure 1.3. All of the members are under compressive forces with the exception of the cables that are in tension. For a typical cable-stayed bridge, the occurrence of high local flexural stresses is mainly

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